NPS ARCHIVE
1963
GREENE, W.

MASTER'S THESIS

WILLIAM GREENE

SAN DIEGO STATE COLLEGE

1963

DUDLEY KNOX LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY CA 93943-5101

Library
U. S. Naval Postgraduate School
Monterey, California

NC4(37)
5000/2
12 Nov 1963

MEMORANDUM

From: Curricular Officer, Engineering Science Programs
To: Librarian

Subj: Masters Degree Thesis; forwarding of

Ref: (a) PGSINST P5000.2B, Article 118

Encl: (1) Masters Thesis by LCDR William F. GREENE, USN, San Diego State College, 1963

1. Enclosure (1) is forwarded in accordance with reference (a).

[illegible]
[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

THE EFFECT OF CRACK LENGTH ON TENSILE PROPERTIES OF HIGH STRENGTH STEELS

A Thesis
Presented to the
Faculty of
San Diego State College

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
in
Mechanical Engineering

by
William Frederick Greene
August 1963

NPS Archive
1963
Greene, W.

Thesis
G753

[illegible]
[illegible]

[illegible]
[illegible]
[illegible]
[illegible]

[illegible]
[illegible]
[illegible]
by
[illegible]

[illegible]
[illegible]

Library
U. S. Naval Postgraduate School
Monterey, California

DUDLEY KNOX LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY CA 93943-5101

TABLE OF CONTENTS

CHAPTER PAGE

I. THE PROBLEM, DEFINITIONS OF TERMS, AND SYMBOLS USED . . . 1
  The Problem . . . 1
    Statement of the problem . . . 1
    Importance of the study . . . 2
  Definitions of Terms Used . . . 2
    Annealing . . . 2
    Austenitizing . . . 2
    Cleavage fracture . . . 2
    Critical crack length . . . 2
    Martensite . . . 3
    Plastic flow . . . 3
    Recrystallization . . . 3
    Shear fracture . . . 3
    Spheroidizing . . . 3
    Tempering . . . 3
  Symbols . . . 4
II. REVIEW OF THE LITERATURE . . . 6
III. THE MATERIALS TESTED AND SPECIMEN GROUPS USED . . . 7
  The Materials Tested . . . 7
  Specimen Groups . . . 7
IV. TECHNIQUE AND RESULTS ON EACH MATERIAL . . . 9
  SAE 4130 . . . 9

CHAPTER PAGE

0.90 16

V. SUMMARY AND CONCLUSIONS 21

Summary 21

Conclusions 22

BIBLIOGRAPHY 24

APPENDIX 26

A. ELONGATION SENSING SYSTEM 27

B. TABLES 31

C. MATERIAL COMPOSITION 34

ABSTRACT 35

LIST OF FIGURES

FIGURE PAGE

1. Specimen Preparation 8
2. Critical Crack Length Curves for SAE 4130 Specimens . . . 14
3. Ductility Plot for SAE 4130 Specimens 15
4. Fracture of SAE 4130 Specimens 17
5. Fracture of 0.90 C Specimens 17
6. Critical Crack Length Curves for 0.90 C Specimens 19
7. Ductility Plot for SAE 0.90 C Specimens 20
8. Block Diagram of Strain Measuring and Recording System . . 28
9. Drawing of LVDT Installation 30

CHAPTER I

THE PROBLEM, DEFINITIONS OF TERMS, AND SYMBOLS USED

I. THE PROBLEM

Statement of the problem. As increasing attention is concentrated on the strength to weight ratio in structural components, a relatively new area of investigation is being examined more closely. This is the effect of cracks on the load carrying capacity of a material. A good example is the motor case of a solid propellent rocket.

There are two fundamental problems associated with crack effects. The first is the determination of a maximum or critical crack length for the design material. Critical crack length is the longest crack length that does not reduce the tensile strength of a material. The existence of such a crack length for different materials has been confirmed experimentally by Bockrath and Glassco (10). * Associated closely with the strength consideration is the measure of ductility remaining in a material containing a crack. This parameter has not been reported by investigators.

The other problem is in the field of inspection technique. It is the identification of all cracks in a material that is as long or longer than the critical crack length.

---

*Parentheses refer to bibliographical items. Page number, when used, follows a colon.

This study was confined to an evaluation of critical crack length and ductility at room temperature.

Importance of the study. While it is known that cracks diminish the load carrying capacity of a material in tension, quantitative information in this area is limited. High strength sheet metal in a thickness of about 0.038 inches has not been investigated for crack sensitivity. Because there is good potential for the use of metals in this approximate thickness in aerospace applications, two different high strength steels in this thickness were chosen for evaluation in crack sensitivity tensile tests.

II. DEFINITIONS OF TERMS USED

Annealing. The term "annealing" pertains to the heating to and holding at a suitable temperature, about 1600°F, then cooling at a suitably slow rate such as in a furnace for such purposes as reducing hardness, producing a desired microstructure, etc.

Austenitizing. "Austenitizing" is the forming of austenite, a solid solution of one or more elements in face centered cubic iron, by heating above the transformation range.

Cleavage fracture. A fracture usually of a polycrystalline metal in which most of the grains have failed by cleavage, resulting in bright reflecting facets, is specified as a "cleavage fracture."

Critical crack length. The longest crack length that does

not reduce the tensile strength of a material is termed the "critical crack length."

Martensite. Specifically "martensite" is an interstitial supersaturated solid solution of carbon in iron, having a body centered tetragonal lattice. Its microstructure is characterized by an acicular or needle like pattern.

Plastic flow. The term "plastic flow" indicates the deformation that remains permanent after removal of the load which caused it.

Recrystallization. The formation of a new strain-free grain structure from that existing in cold worked metal, usually accomplished by heating, indicates "recrystallization."

Shear fracture. A "shear fracture" is a fracture in which a crystal has separated by sliding or tearing under the action of shear stresses.

Spheroidizing. The heating and cooling to obtain a globular form of carbide, (Fe_3C), in steel is termed "spheroidizing."

Tempering. The act of "tempering" is the reheating of a quench-hardened ferrous alloy to a temperature below the transformation range and then cooling at any desired rate.

III. SYMBOLS

W	The specimen width, in inches
t	The specimen thickness, in inches
A	Gross cross sectional area at the crack, (W x t), in square inches
P	Maximum load sustained by a cracked specimen before fracture, in pounds
L	Length of crack, in inches
Lo	Critical crack length, in inches
$\frac{L}{W}$	Length of crack, in inches per inch of specimen width
$1- \frac{L}{W}$	Net uncracked width in inches per inch of specimen width
S	Gross tensile stress at crack cross section, under maximum load, $\frac{P}{A}$, in pounds per square inch
Sn	Net tensile stress at crack cross section, under maximum load, $\frac{S}{1 - \frac{L}{W}}$, in pounds per square inch
Rc	The average of six values of hardness taken on the specimen, using the Rockwell "C" scale

Su	Ultimate tensile strength in pounds per square inch, of a group of specimens determined by conversion of the average Rc of the group
$\frac{Sn}{Su}$	Ratio of the net tensile stress to the average ultimate tensile stress, at the maximum load
D	Ductility, or the elongation under load at failure, of a two inch gauge length, taken across the specimen crack, in per cent

CHAPTER II

REVIEW OF THE LITERATURE

This study was prompted by a curiosity concerning the crack sensitivity of high strength engineering materials in sheet form. There has been considerable discussion of applications of these materials in major technical publications recently. The most closely related articles are listed in the bibliography.

A paper by Bockrath and Glassco (8), contained the best discussion of crack sensitivity. They reported data on several metals in thicknesses greater than was chosen for this study. Some ideas in data correlation found in their paper were useful in guiding the analysis of data in this investigation.

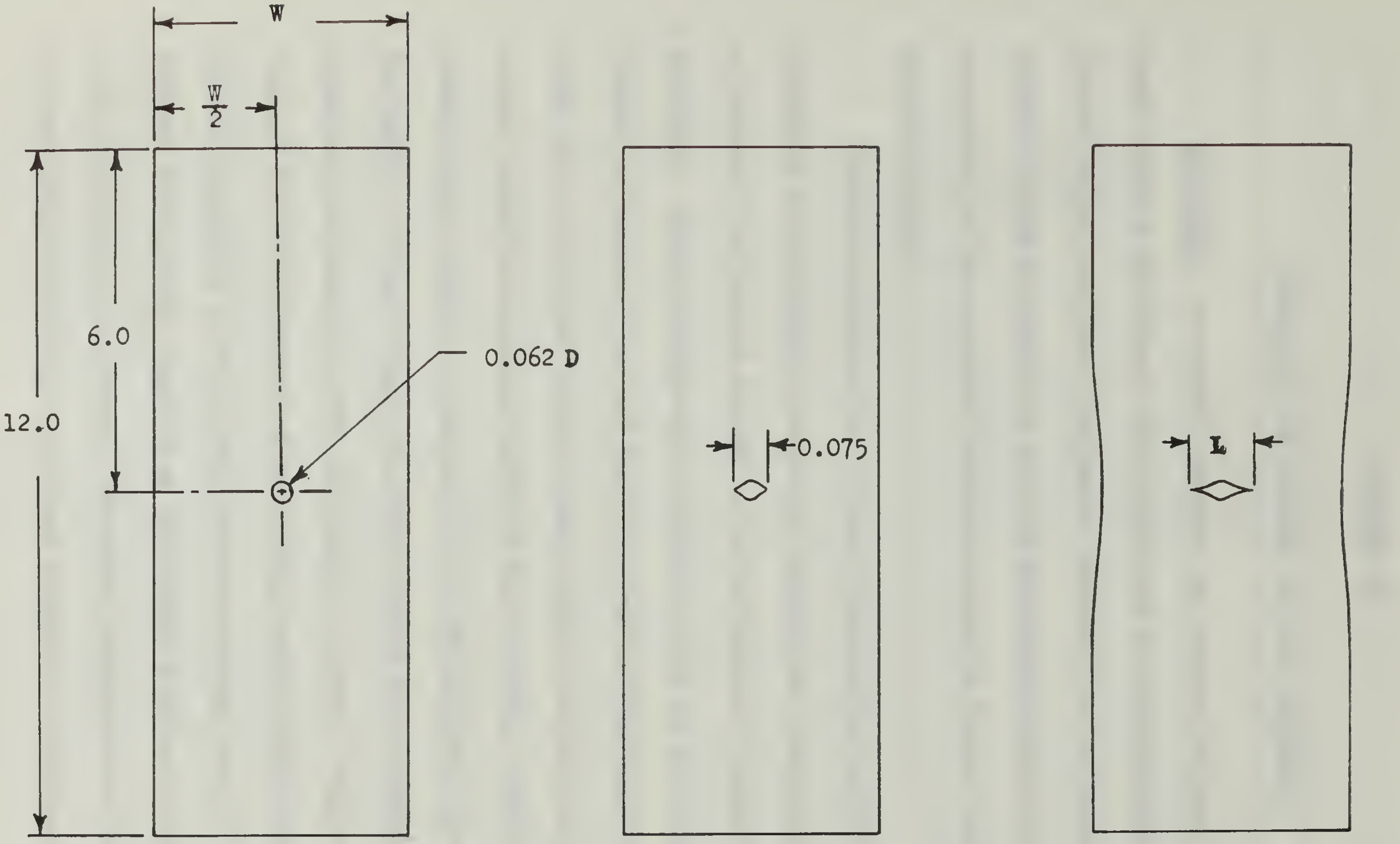
CHAPTER III

THE MATERIALS TESTED AND SPECIMEN GROUPS USED

The materials tested. Two materials were studied; they were a chromium-molybdenum low alloy steel, SAE 4130 containing 0.31 per cent carbon, and a stronger, less ductile oil hardening steel containing 0.90 per cent carbon. The chemical analyses of these steels is listed in Appendix C.

These materials represent two extremes in high tensile sheet steels. The former steel is easily worked mechanically and has excellent welding properties. It is used widely in airframe structural applications. The oil hardening steel, while having a higher tensile strength than SAE 4130, is more difficult to work mechanically and poses welding problems. These steels will be referred to hereinafter as SAE 4130 and 0.90 C.

Specimen groups. Specimen sizes were chosen to furnish the widest range of data possible using available testing facilities. All specimens were of rectangular shape, were 12 inches long, and were 0.038 inches thick. Widths of 2, 3, and 4 inches were prepared in each type of material. A group of each width was centrally drilled simultaneously and then notched as shown in Figure 1, page 8.



DRILLED

DRILLED
AND NOTCHED

DRILLED-NOTCHED
AND CRACKED IN TENSION

FIGURE 1 SPECIMEN PREPARATION

[illegible]

CHAPTER IV

TECHNIQUE AND RESULTS ON EACH MATERIAL

SAE 4130. An effort was made to produce fatigue cracks in sheet tensile specimens. This could not be satisfactorily accomplished using available equipment. However, it was possible to produce cracks in centrally drilled and notched sheet tensile specimens, in the annealed condition, using a Riehle tensile testing machine.

Sheet specimens of 2, 3, and 4 inch widths and 0.038 inches thickness were prepared, centrally drilled and then notched, using a jewelers file ground sharply so as to produce a notch as sharp as possible. Sharp notches were desired so that as the specimen was loaded in tension, the peak tensile stress at the base of the notch would rise to a level several times higher than the average tensile stress across the specimen width at that section. This higher stress caused localized plastic flow of the material at the base of the notch. At that stage, the entire width cross section at the crack was stressed well into the plastic region. This was clear because the width diminished noticeably during crack propagation. Such a phenomenon is frequently termed "necking down." With the slowest strain rate possible on the Riehle machine, which was less than 0.025 inches per minute, the crack propagation in this steel was very slow. In fact, nearly any length of crack could be

obtained by simply relaxing the load on the specimen when the desired crack length was obtained. Using this method, approximately ten specimens having different crack lengths were obtained in each specimen width. These cracked specimens were then heat treated to a much higher tensile strength. Groups of ten were heated together in an argon gas controlled atmosphere electric furnace, using aluminum and charcoal powders to inhibit decarburization and oxidation. They were held at 1600°F, (Fahrenheit), for one and one-half hours to permit the following conditions to prevail:

(1) Recrystallization of the structure that had been cold worked in the cracking process,

(2) Uniformity of temperature within each specimen at the holding temperature, and

(3) To promote maximum austenitization and solution of carbon while limiting grain growth.

Each specimen was individually quenched in a 10 per cent brine solution from the elevated temperature, which transformed the austenite to martensite. Only slight distortion of specimens was experienced with this severe quenching.

Six hardness readings were taken near the crack and recorded for each specimen. The tempering of each specimen was determined on the basis of its as-quenched hardness, since uniform hardness of specimens was desired in order that fair comparisons could be made from results of the tensile tests that were to follow. A typical

tempering treatment involved a group of specimens having an average Rockwell "C" scale hardness of 52. They were tempered at 300°F for three hours in an electric furnace. Some specimens required more than one tempering in order to obtain uniform hardness. Three specimens were re-tempered at 700°F, where the holding time was limited to one hour because of the rapid softening of the specimens at that temperature. The average of six hardness values taken from each specimen after tempering was recorded in the Rc column in the summarized data of Table 1 in Appendix B.

The final operation in each type of material was the tensile test to fracture of each specimen. In each case, the maximum load sustained was tabulated in column P of Table 1. The strain rate for all specimens was 0.025 inches per minute. Ductility information was recorded during the tensile test on a Minneapolis Honeywell Visicorder, using a strain sensing system described in Appendix A. Using this equipment in conjunction with the Riehle tensile testing machine, continuous load in pounds versus elongation in inches was recorded up to failure for a two inch guage length of each sheet tensile specimen. The following measurements were taken and recorded in Table 1:

(1) Minimum specimen width, W, before fracture, across the cracked section, using a vernier caliper.

(2) Average specimen thickness, t, before fracture, using a round anvil micrometer caliper.

(3) Crack length, L, after fracture, using a vernier caliper. L refers to the length of crack that was generated in a specimen before heat treatment. In a fractured specimen the crack ends were obvious because of the difference in color between the crack and fractured metal.

Analysis of the data from several different viewpoints resulted in the following procedure and curves. A log-log plot of the ratio S_n/S_u versus L indicated a straight line relationship. A linear plot of D versus L showed the clearest correlation for the evaluation of ductility.

The S_n/S_u ratio was obtained in the following manner:

$S = \frac{P}{A}$ = Gross tensile strength

$S_n = \frac{S}{1 - \frac{L}{W}}$ = Net tensile strength

S_u is the ultimate tensile strength of the average specimen in a width group as determined from hardness value conversion.

Division of S_n by S_u so obtained, yields the desired ratio for a single specimen, which is tabulated in Table I, page 31.

An explanation of the hardness value averaging and the conversion to ultimate strength methods follow.

The Rc values of several specimens of the same width taken from Table I were averaged. This value was then converted to an average ultimate tensile strength S_u, for that group, using

a standard conversion table. The validity of this conversion was confirmed by preparing an additional set of four plain tensile test specimens for both materials tested. The specimen numbers for SAE 4130 were 70, 71, 72, and 73, and for the 0.90 C they were 74, 75, 76, and 77. Heat treatment was the same as for the cracked specimens. The average deviation of actual tensile strength determined from these eight specimens with values obtained from conversion of specimen average hardness values was 1.1 per cent. This is considered to be consistent with the accuracy of the test data and therefore justified use of the ultimate strength obtained by converting the average Rockwell hardness values to S_u for groups. With a common S_u for a single width group, a simple correlation of results was possible in the ratio S_n/S_u.

Figure 2, page 14, shows the relationship between S_n/S_u and L for each specimen width. The intercept of the resulting straight line and the unit value for S_n/S_u yields the critical crack length, Lo, for that width of specimen. This is reasonable because when S_n/S_u has a value of unity there has been no loss of strength in the specimen.

Figure 3, page 15, shows the relationship between D and L for each specimen width. Data for specimens 3-1/2 inches wide was plotted also. They had been used in a preliminary study and although the hardness variation was too great to permit fair analysis of cracked strength, the ductility data reinforced all

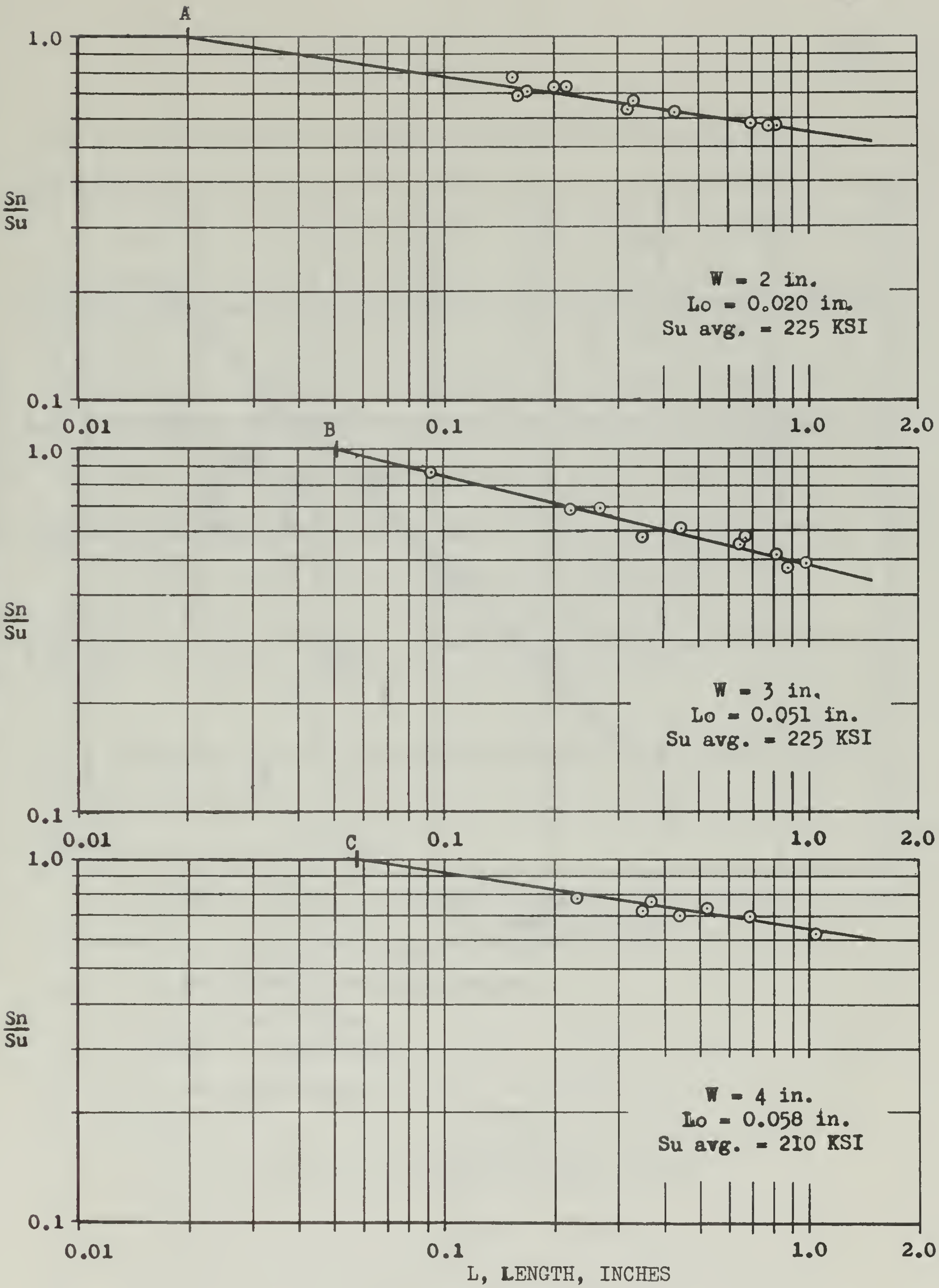


FIGURE 2

CRITICAL CRACK LENGTH CURVES FOR SAE 4130 SPECIMENS

[illegible]

[illegible]

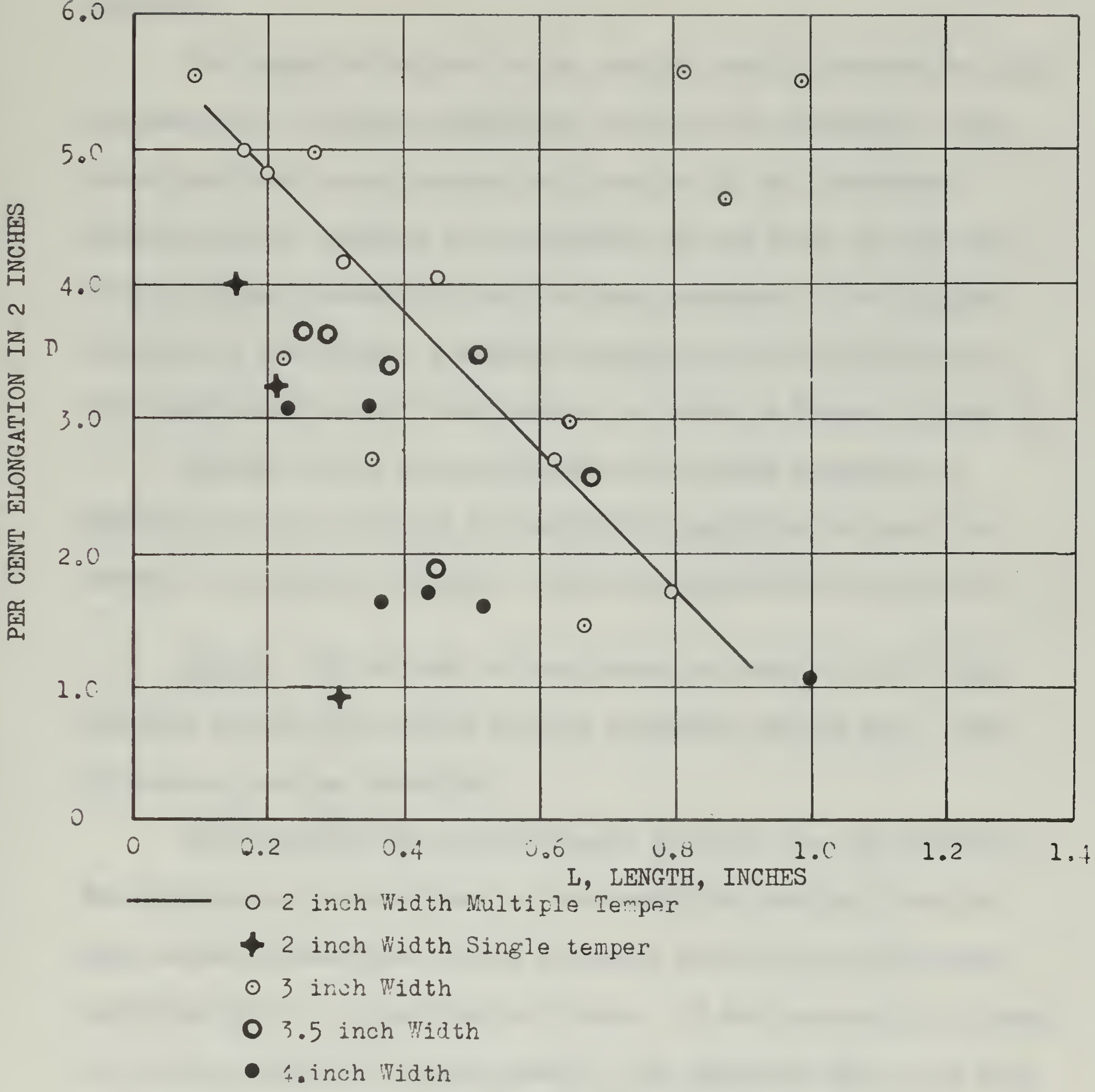


FIGURE 3

DUCTILITY PLOT FOR SAE 4130 SPECIMENS

other ductility data as plotted in Figure 3 and was therefore included.

The manner of failure in the tensile test of cracked SAE 4130 specimens was a typical combination of shear and cleavage. These terms have been called ductile and brittle, in the literature. Failures always occurred as an extension of the crack on each side of the specimen centerline that had been produced in the specimen before heat treatment. A typical fracture was at right angles to the longitudinal axis of the specimen as shown in Figure 4, page 17.

Typical stress strain diagrams for cracked specimens in SAE 4130 and 0.90 C showed no significant departure in form from curves for uncracked material. They are excluded for this reason.

0.90 C. The methods of preparation and testing this steel followed closely the methods already described for SAE 4130. The differences are now described.

This material was more difficult to crack than the SAE 4130. The difference was attributed to low ductility resulting from the high carbon content even though the steel was in the spheroidized condition prior to generation of cracks. It was especially difficult to obtain a crack in a length greater than three-eighths of an inch in specimens two inches wide. Under these conditions several specimens failed abruptly in a brittle manner. In heat treatment the austenitizing temperature was 1525°F and the quench medium was oil. Distortion in quenching was very slight for these samples.

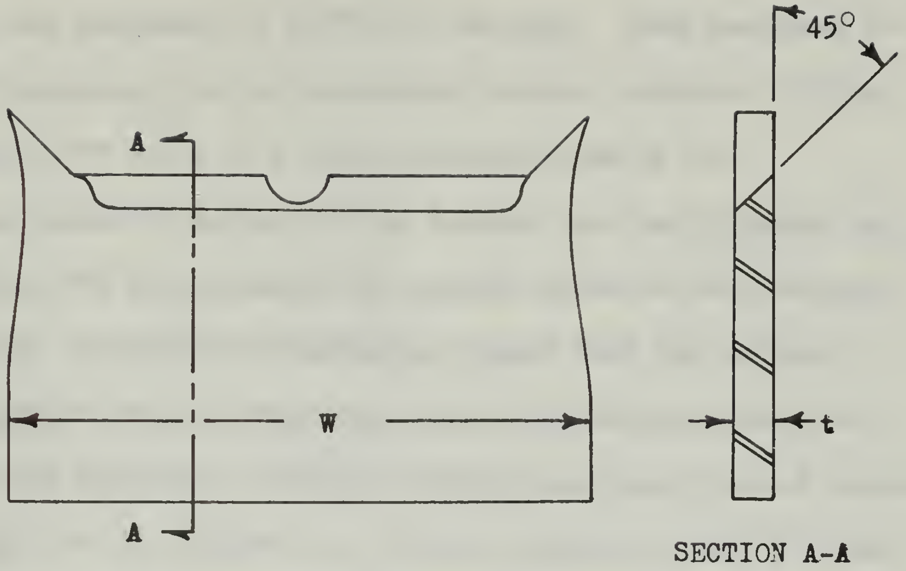


FIGURE 4

FRACTURE OF SAE4130 SPECIMENS

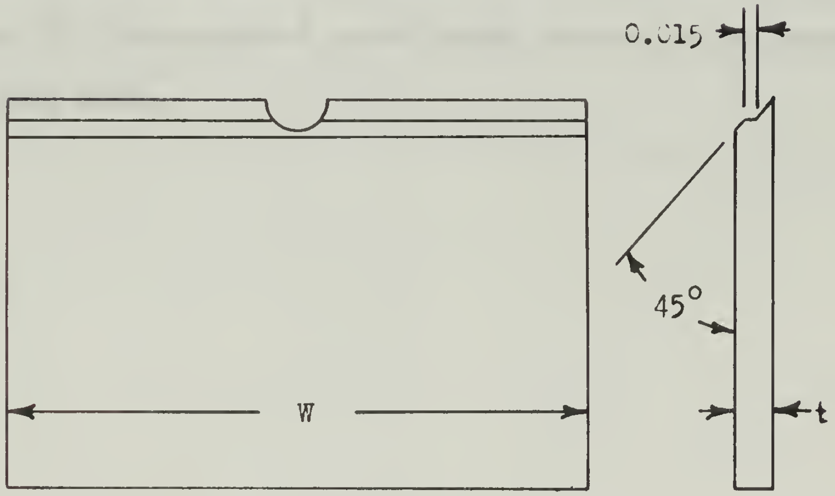
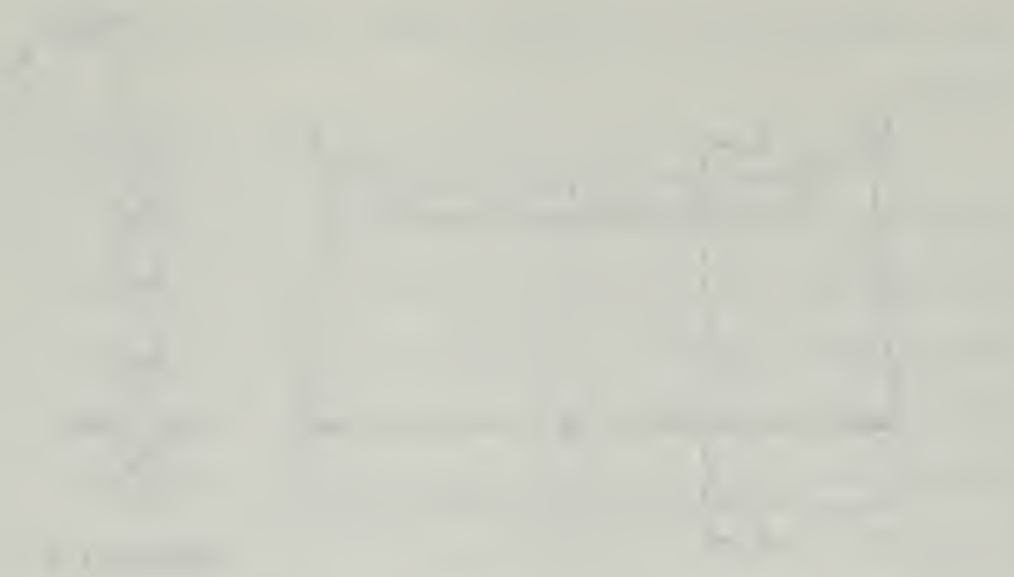


FIGURE 5

FRACTURE OF 0.90 C SPECIMENS



[illegible]

[illegible]

[illegible]

[illegible]

Tempering was performed at 700°F for one hour. Some specimens required retempering from the as-quenched average hardness of 67 on the Rockwell "C" scale to a nearly uniform value of 51.

The manner of failure in the tensile test was cleavage and shear again, but they occurred in opposite order to the fractures of SAE 4130. Macroscopic examination showed that the initial internal failure was cleavage for about 0.015 inches across the center of the thickness, changing rapidly to a shear type of failure to each edge of the specimen, as shown in Figure 5, page 17. The failure was nearly instantaneous across the entire width. This contrasts with the slower failure and continued extension of the SAE 4130 cracked specimens after a fracture started. The initiation of failure at the central longitudinal axis in tensile specimens is presented clearly by Johnson and Mellor (3:8). Figures 6, page 19, and 7, page 20, show critical crack length curves and the ductility plot, in that order.

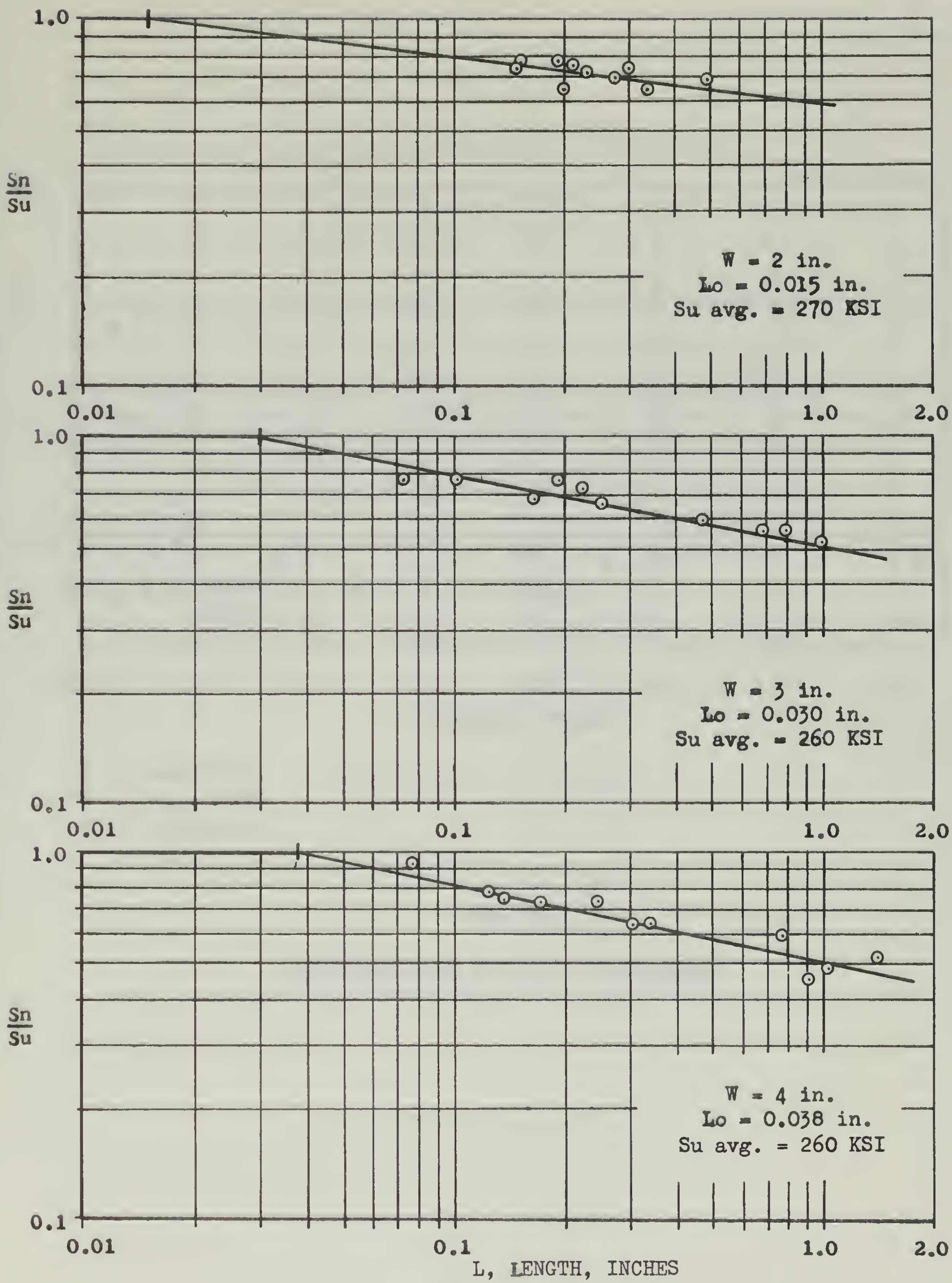


FIGURE 6

CRITICAL CRACK LENGTH CURVES FOR 0.90 C SPECIMENS

[illegible]

[illegible]

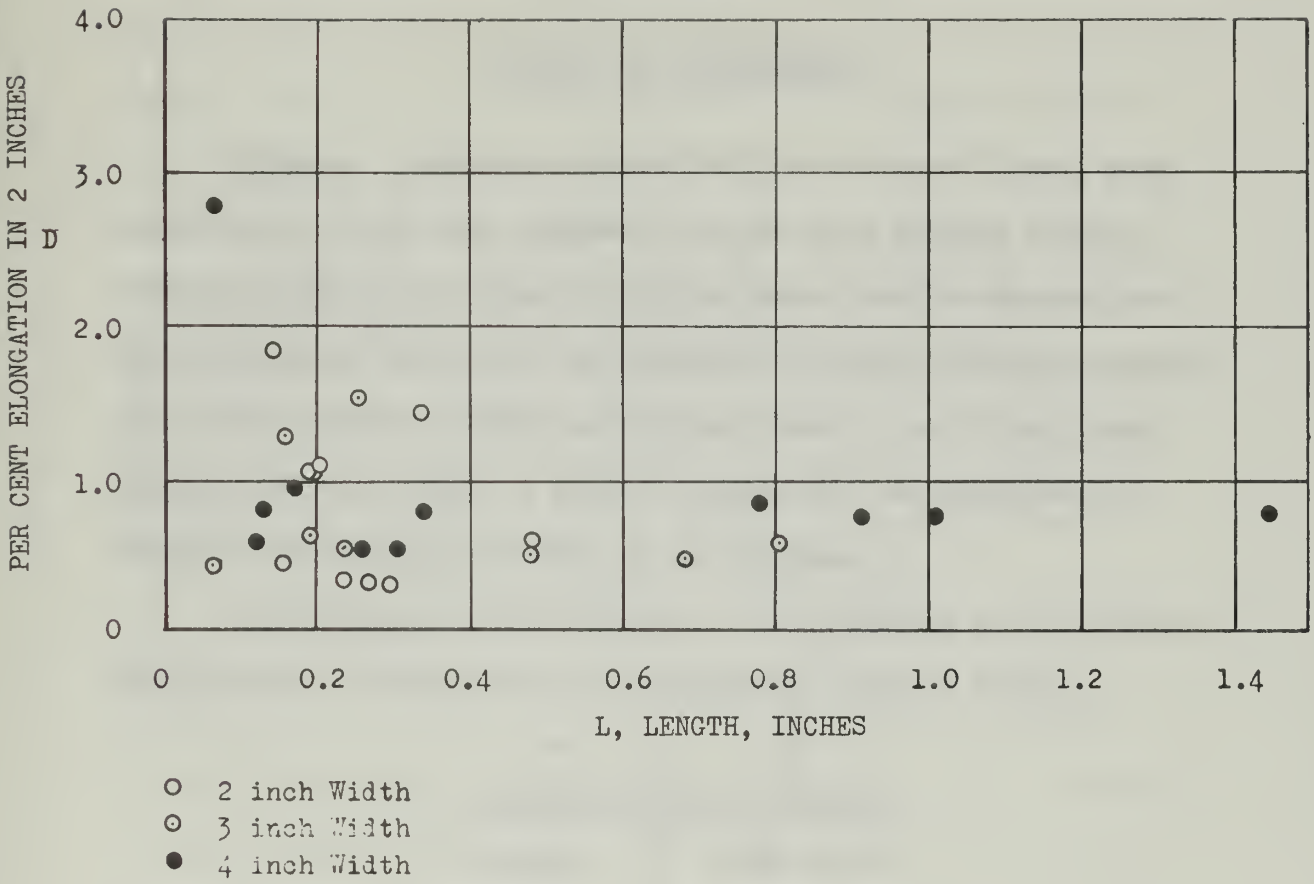


FIGURE 7

DUCTILITY PLOT FOR 0.90 C SPECIMENS

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary. Centrally cracked SAE 4130 and 0.90 C sheet steel specimens in 0.038 inch thickness that are heat treated to high strength levels are subject to failure under tensile stresses that are appreciably lower than the material's ultimate tensile strength. For a given specimen width and hardness there is a critical crack length such that cracks of shorter length will not diminish the tensile load carrying capacity of the specimen.

Considering the SAE 4130 steel, the following are the critical crack lengths, determined for the indicated specimen widths:

W	Lo
2 inches	0.020 inch
3 inches	0.050 inch
4 inches	0.058 inch

Critical crack lengths for the 0.90 C specimens were found to be as follows:

W	Lo
2 inches	0.015 inch
3 inches	0.030 inch
4 inches	0.038 inch

Ductility for each material is not as clearly defined on the basis of these tests as shown by Figures 3 and 7. The ductility at critical crack length is approximately 5 per cent for SAE 4130 and 1 per cent for 0.90 C.

Conclusions. An indication of the critical crack length for each material tested, but in an infinitely wide sheet may be inferred from the composite plot of the three curves in each of Figures 2 and 6. They show a definite trend toward a limit for critical crack length in specimen widths of increasing size. If a curve were to be drawn through the points marked A, B, and C in Figure 2 it could become asymptotic to L equal to 0.065 inch. A similar process applied to Figure 6 would produce an asymptote, L equal to 0.050 inch. It is therefore recommended that a technique be developed to investigate specimen widths greater than 4 inches in an effort to determine the width of specimen that will closely approximate the critical crack length of an infinitely wide sheet.

The heat treatment of all specimens evaluated in this study was directed toward uniform hardness and strength. A general relationship of ductility to crack length cannot be inferred from Figures 3 and 7. More consistent results should be obtained with different heat treating facilities. In particular, a salt bath for austenitizing prior to quenching would help to insure structural uniformity in specimens and to prohibit decarburization. In this manner a more complete transformation to martensite would be

possible in the subsequent quenching. Also, if salt bath tempering could be performed, more consistent hardness and strength levels would be obtained with identical tempering practice. In this manner irregular re-tempering that was required in this study could be eliminated. Consequently, ductility data would reflect the more closely controlled heat treatment. Klinger, et al., (4:1557), proposed that brittleness, and hence variation in ductility, stems from a thin ferrite network adjacent to the former austenitic grain boundaries. Apparently the cause is an overaging process which, in turn, is a function of time at a tempering temperature.

BIBLIOGRAPHY

BIBLIOGRAPHY

A. BOOKS

1. Clark, Donald S., and Wilbur R. Varney. *Metallurgy for Engineers*. Second edition. Princeton: D. Van Nostrand Company, 1962.

2. Grover, H. J., S. A. Gordon, and L. R. Jackson. "Fatigue of Metals and Structures," *Report of Batelle Memorial Institute*, prepared for the Bureau of Aeronautics, Department of the Navy, Publication NAVAER 00-25-534. Washington: Government Printing Office, 1954.

3. Johnson, W., and P. B. Mellor. *Plasticity for Mechanical Engineers*. First edition. London: D. Van Nostrand Company, 1962.

4. Klinger, L. J., and others. *The Embrittlement of Alloy Steel at High Strength Levels*. Metals Park, Ohio: Transactions of the American Society for Metals, 1954.

5. Lyman, Taylor, and others. *Metals Handbook*. Eighth edition. Metal Park, Ohio: American Society for Metals, 1961.

6. Muhlenbruch, Carl W. *Experimental Mechanics and Properties of Material*. Second edition. Princeton: D. Van Nostrand Company, 1955.

B. PAPERS AND PERIODICAL ARTICLES

7. *Almar Maraging Steels*. Pittsburgh: Allegheny Ludlum Steel Corporation, 1962.

8. Bockrath, G. E., and J. B. Glassco. *Fracture Toughness of High Strength Sheet Metal*. Engineering Paper Number 1607, Douglas Missle and Space Systems Division. Santa Monica, California, 1963.

9. *Nominal 200KSI Yield Strength 18 Percent Nickel Maraging Steel*. New York: The International Nickel Company, 1962.

10. Ward, W. V. "The Maraging Steels, a New Concept in Metallurgy." *Western Machinery and Steel World*, March, 1963.

APPENDICES

APPENDIX A

ELONGATION SENSING SYSTEM

The strain measuring devices available were limited to the elastic elongation range of test specimens because of the short linear range of the transducers mounted on them. Therefore, an Extensometer Sensing System was developed to produce a continuous recording of specimen strain versus load, up to and including tensile failure. Figure 8, page 28, illustrates the arrangement of components. A description of this system follows.

The strain pickup, attached to the test specimen was a linear Variable Differential Transformer, (LVDT), an electro-mechanical transducer. It translates very small linear displacements into measurable voltage differences. A Schaevitz LVDT, model number E-300D was selected. Repeatable voltage output of infinite resolution and the ability to withstand specimen failure shock were the reasons for this choice.

A Regulator Demodulator, Schaevitz model number DMPS-1 was used to furnish a regulated a.c. input to the LVDT and to rectify, demodulate, and filter the output. A cathode follower circuit was designed and built to feed the demodulator d.c. output into a Minneapolis Honeywell (M. H.) Recording Oscillograph. Input impedance was 2,000 ohms, to match the demodulator. An output impedance of 55 ohms matched the M. H. Galyanometer model number

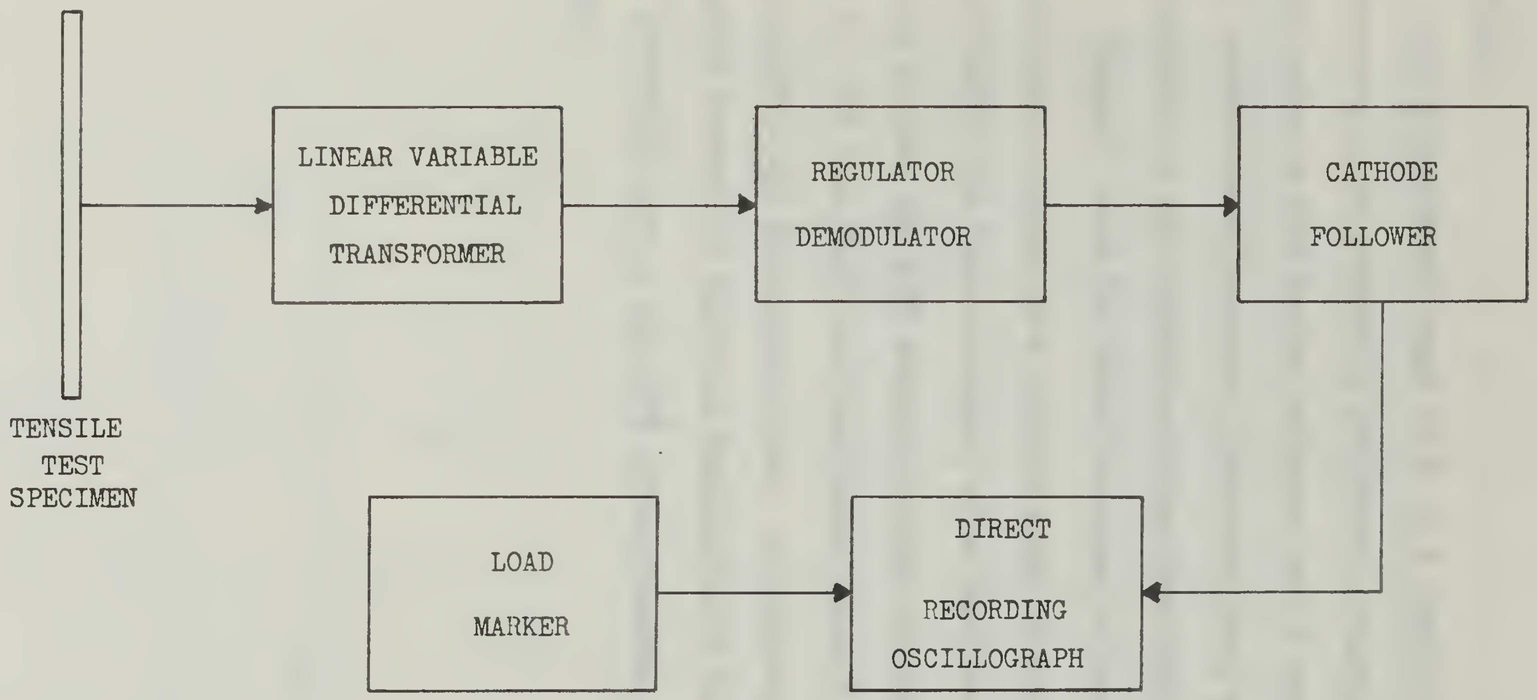

LINEAR VARIABLE DIFFERENTIAL TRANSFORMER
REGULATOR DEMODULATOR
CATHODE FOLLOWER
TENSILE TEST SPECIMEN
LOAD MARKER
DIRECT RECORDING OSCILLOGRAPH

FIGURE 8

BLOCK DIAGRAM OF STRAIN MEASURING AND RECORDING SYSTEM

[illegible]

[illegible]

[illegible]

M-200-120.

The galvanometer image on M. H. 8 inch wide, instant trace, photographic paper produced a continuous elongation curve. A load marker, using an SPDT switch in series with a battery to drive a M. H. M-8000-120 Galvanometer, permitted entry of load information when desired, on the elongation versus time trace.

Figure 9, page 30, shows the manner in which the LVDT was connected to a typical test specimen prior to fracture. A strip of strong double-back tape one-eighth of an inch wide and one inch long was used to bond the LVDT terminals firmly to the test specimen at A and B. The tape width was distributed equally on each side of the respective two inch gauge lines. In this manner an average elongation across the crack was transmitted by the LVDT as its core moved vertically out of the LVDT during specimen loading in tension.

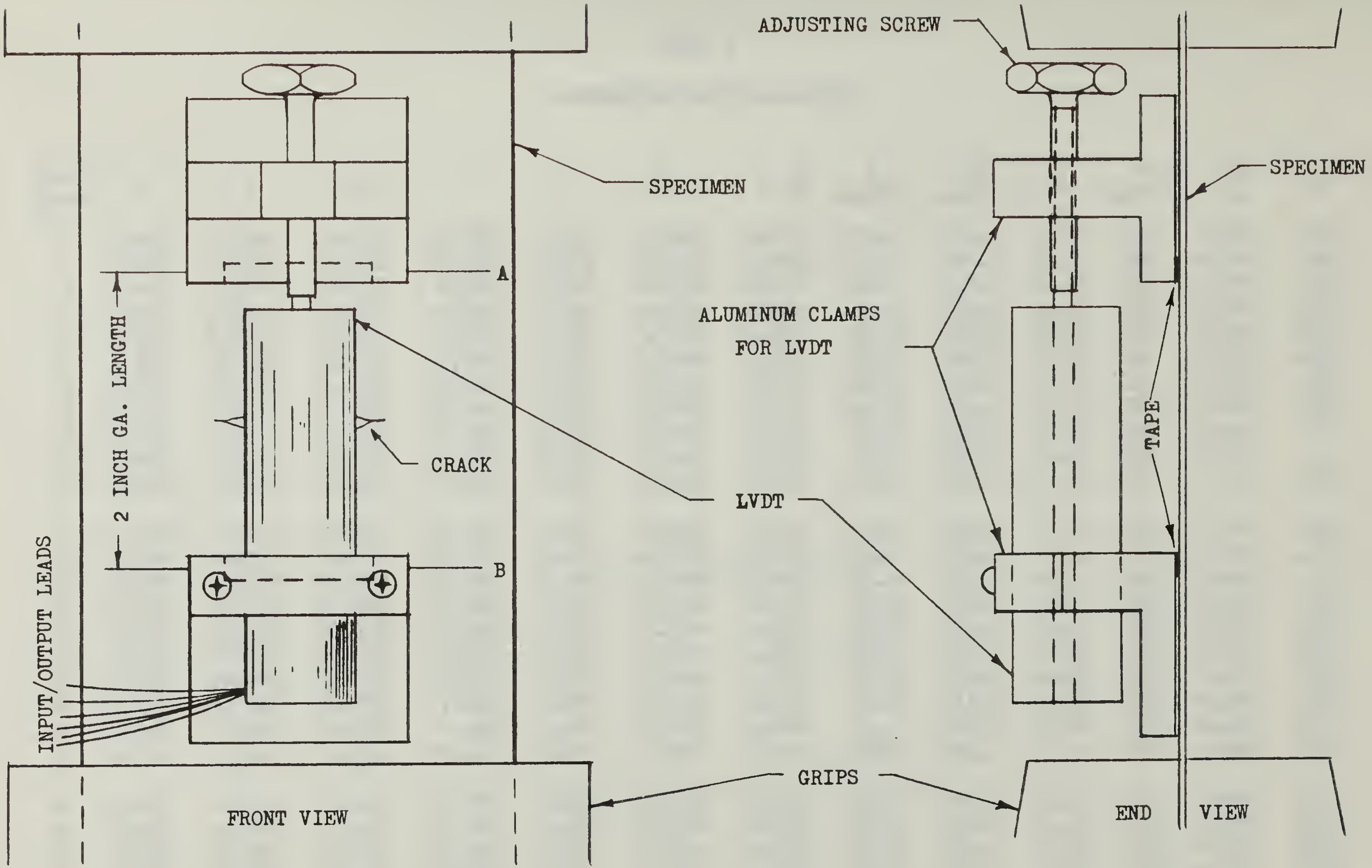


FIGURE 9

DRAWING OF LVDT INSTALLATION

[illegible]

[illegible]

TABLE I

SUMMARIZED DATA SAE 4130

Specimen	W	t	A	P	L	$\frac{L}{W}$	$1-\frac{L}{W}$	S $\times10^{-3}$	Sn $\times10^{-3}$	Rc	Su $\times10^{-3}$	$\frac{Sn}{Su}$	D
1	1.907	0.0365	0.0696	11,050	0.154	0.0808	0.919	158.8	172.8	47.0	225	0.768	4.00
2	1.900	0.0365	0.0694	10,060	0.219	0.1152	0.885	145.0	163.9	47.4	225	0.728	3.25
3	1.897	0.0377	0.0715	8,575	0.310	0.1634	0.837	119.9	143.3	46.3	225	0.637	0.92
4	1.843	0.0355	0.0654	4,820	0.804	0.4362	0.564	73.8	131.0	46.5	225	0.582	1.72
5	1.859	0.0385	0.0715	5,850	0.693	0.3728	0.627	81.8	130.3	47.7	225	0.579	2.70
6	1.906	0.0363	0.0692	8,550	0.316	0.1658	0.834	123.6	148.2	47.4	225	0.659	4.16
7	1.947	0.0370	0.0720	10,400	0.200	0.1027	0.897	144.5	161.1	45.9	225	0.716	4.84
8	1.933	0.0367	0.0709	10,000	0.168	0.0869	0.913	141.0	154.4	45.6	225	0.686	5.00
9	1.958	0.0375	0.0734	10,400	0.160	0.0817	0.918	141.7	154.3	47.2	225	0.686	--
10	1.861	0.0355	0.0661	4,850	0.790	0.4245	0.576	73.4	127.5	46.4	225	0.567	--
11	1.898	0.0360	0.0683	7,675	0.426	0.2244	0.776	112.4	144.9	46.6	225	0.644	4.07
12	2.900	0.0370	0.1073	15,210	0.223	0.0769	0.923	141.8	153.6	44.8	225	0.683	3.64
13	2.889	0.0373	0.1078	15,240	0.270	0.0935	0.907	141.4	156.0	48.4	225	0.693	4.50
14	2.870	0.0368	0.1056	12,100	0.450	0.1568	0.843	114.6	135.9	46.2	225	0.604	--
15	2.859	0.0359	0.1026	9,800	0.650	0.2274	0.773	95.5	123.6	46.3	225	0.549	3.00
16	2.852	0.0348	0.0992	9,825	0.672	0.2356	0.764	99.0	129.6	46.0	225	0.576	1.48
17	2.870	0.0352	0.1010	11,450	0.353	0.1230	0.877	113.4	129.3	46.0	225	0.575	2.71
18	2.842	0.0360	0.1023	8,450	0.815	0.2868	0.713	82.6	115.8	48.0	225	0.515	5.60
19	2.806	0.0347	0.0974	7,010	0.996	0.3549	0.645	72.0	111.5	45.5	225	0.496	5.01
20	2.848	0.0353	0.1005	7,450	0.877	0.3079	0.692	74.1	107.1	45.8	225	0.476	4.60
21	2.992	0.0345	0.1032	19,475	0.092	0.0307	0.969	188.7	194.7	47.5	225	0.865	5.54
22	3.830	0.0380	0.1455	17,300	0.680	0.1775	0.823	119.0	144.5	44.7	210	0.689	1.60
23	3.851	0.0380	0.1463	14,060	1.060	0.2726	0.727	96.1	132.2	44.3	210	0.630	1.10
24	3.879	0.0380	0.1474	19,750	0.521	0.1343	0.866	134.0	154.7	43.5	210	0.737	1.62
25	3.901	0.0380	0.1482	21,450	0.371	0.0951	0.905	144.7	159.8	46.0	210	0.761	1.62
26	3.899	0.0380	0.1482	19,350	0.440	0.1130	0.887	130.5	147.1	45.6	210	0.700	1.72
27	3.621	0.0380	0.1376	18,650	0.350	0.0968	0.903	135.5	150.0	44.9	210	0.714	3.10
28	3.900	0.0380	0.1482	22,850	0.230	0.0590	0.941	154.1	163.8	42.1	210	0.780	3.10

TABLE I

SUMMARIZED DATA CONTINUED

Specimen	W	t	A	P	L	$\frac{L}{W}$	$1-\frac{L}{W}$	S $x10^{-3}$	Sn $x10^{-3}$	Rc	Su $x10^{-3}$	$\frac{Sn}{Su}$	D
SAE 4130 DUCTILITY ONLY													
63	3.401	0.0390	0.1326	18,000	0.390	0.1148	0.885	135.7	153.3	44.6	--	--	7.50
64	3.380	0.0380	0.1284	17,000	0.680	0.2010	0.799	132.4	165.7	43.1	--	--	2.52
65	3.382	0.0400	0.1353	16,975	0.511	0.1510	0.849	125.5	147.8	36.1	--	--	3.50
66	3.409	0.0398	0.1357	20,350	0.290	0.0850	0.915	150.0	163.9	41.0	--	--	3.66
67	3.389	0.0380	0.1288	19,150	0.450	0.1330	0.867	148.7	171.5	49.0	--	--	1.84
68	3.399	0.0381	0.1295	19,600	0.381	0.1118	0.888	151.4	170.5	37.1	--	--	3.40
69	3.410	0.0390	0.1330	20,925	0.239	0.0701	0.930	157.3	169.1	48.4	--	--	3.65
SAE 4130 TENSILE ONLY													
													Su % Error
70	1.992	0.0385	0.0760	11,560	--	--	--	150.7	--	34.3	154.2	--	2.3
71	2.010	0.0385	0.0774	11,650	--	--	--	150.5	--	34.1	153.6	--	1.4
72	1.975	0.0385	0.0760	11,525	--	--	--	151.6	--	34.5	155.2	--	2.4
73	1.952	0.0385	0.0752	11,775	--	--	--	156.6	--	35.0	157.5	--	0.6
0.90 PERCENT CARBON DIE STEEL TENSILE ONLY													
74	1.999	0.0383	0.0765	16,120	--	--	--	210.7	--	44.4	209.8	--	0.4
75	2.002	0.0380	0.0761	15,270	--	--	--	200.5	--	42.7	198.6	--	0.95
76	1.992	0.0380	0.0757	15,970	--	--	--	211.0	--	44.6	209.1	--	0.9
77	2.002	0.0380	0.0761	15,750	--	--	--	207.2	--	44.0	207.0	--	0

TABLE II
SUMMARIZED DATA 0.90 PERCENT CARBON DIE STEEL

Specimen	W	t	A	P	L	$\frac{L}{W}$	$1-\frac{L}{W}$	S $\times 10^{-3}$	Sn $\times 10^{-3}$	Rc	Su $\times 10^{-3}$	$\frac{Sn}{Su}$	D
29	1.969	0.0380	0.0748	12,410	0.210	0.1067	0.893	165.9	185.8	46.9	245	0.758	1.10
30	1.978	0.0380	0.0751	12,640	0.195	0.0987	0.901	168.4	187.0	49.2	245	0.763	1.06
31	2.004	0.0390	0.0781	9,860	0.488	0.2441	0.756	126.3	167.1	48.9	245	0.682	0.69
32	1.973	0.0385	0.0760	12,550	0.150	0.0760	0.924	165.0	178.7	50.2	245	0.729	1.87
33	1.970	0.0390	0.0767	10,800	0.200	0.1014	0.899	140.7	156.5	48.1	245	0.639	1.10
34	1.971	0.0380	0.0749	9,760	0.340	0.1726	0.827	130.3	157.5	48.0	245	0.643	1.45
35	1.970	0.0375	0.0739	16,600	0.082	0.0416	0.958	224.6	234.4	51.3	245	0.957	--
36	1.995	0.0386	0.0770	19,350	0.075	0.0376	0.962	251.3	260.0	50.2	260	1.000	4.10
37	1.966	0.0378	0.0743	12,350	0.231	0.1175	0.883	166.2	188.2	51.1	260	0.724	0.38
38	1.977	0.0377	0.0745	13,460	0.152	0.0769	0.923	180.7	195.8	50.6	260	0.753	0.48
39	1.972	0.0373	0.0736	12,000	0.300	0.1521	0.848	163.0	192.2	51.4	260	0.739	0.37
40	1.956	0.0377	0.0737	11,300	0.274	0.1400	0.860	153.3	178.3	50.2	260	0.686	0.36
41	1.995	0.0377	0.0752	13,375	0.215	0.1078	0.892	177.9	199.4	50.2	260	0.767	4.10
42	2.942	0.0380	0.1118	20,550	0.195	0.0663	0.934	183.8	196.8	50.6	260	0.757	0.65
43	2.942	0.0380	0.1118	11,750	0.805	0.2738	0.726	105.1	144.7	48.1	260	0.557	0.61
44	2.989	0.0377	0.1127	21,850	0.074	0.0248	0.975	193.9	198.8	51.3	260	0.765	0.49
45	2.968	0.0400	0.1188	20,425	0.168	0.0566	0.943	171.9	182.3	52.8	270	0.675	1.31
46	2.968	0.0370	0.1099	19,750	0.227	0.0765	0.924	179.7	194.5	51.5	270	0.720	0.57
47	2.961	0.0377	0.1117	22,000	0.103	0.0348	0.965	197.0	204.1	52.4	270	0.756	--
48	2.968	0.0372	0.1104	17,950	0.259	0.0873	0.913	162.6	178.1	51.2	270	0.660	1.53
49	2.964	0.0380	0.1136	15,200	0.473	0.1595	0.841	135.0	160.5	51.6	270	0.594	0.59
50	2.958	0.0377	0.1115	12,600	0.693	0.2343	0.766	113.0	147.5	51.7	270	0.546	0.59
51	2.944	0.0382	0.1125	10,250	1.015	0.3450	0.655	91.1	139.1	52.3	270	0.515	--
52	3.982	0.0380	0.1514	35,800	0.077	0.0194	0.981	236.5	241.1	50.2	260	0.927	2.80
53	3.945	0.0380	0.1500	13,400	0.922	0.2337	0.766	89.4	116.7	49.4	260	0.448	0.77
54	3.965	0.0380	0.1507	28,000	0.139	0.0350	0.965	185.8	192.5	51.3	260	0.740	0.77
55	3.960	0.0380	0.1504	23,000	0.342	0.0864	0.914	152.9	167.3	51.3	260	0.643	0.77
56	3.954	0.0376	0.1487	22,500	0.307	0.0777	0.922	151.3	164.1	51.4	260	0.631	0.64
57	3.953	0.0373	0.1473	18,300	0.780	0.1972	0.803	124.2	154.7	50.7	260	0.595	0.87
58	3.943	0.0378	0.1490	13,620	1.050	0.2664	0.734	91.4	124.5	50.6	260	0.479	0.79
59	3.940	0.0380	0.1498	12,950	1.415	0.3590	0.641	86.4	134.8	50.0	260	0.518	0.99
60	3.967	0.0378	0.1500	27,550	0.173	0.0436	0.956	183.7	192.2	52.2	260	0.739	0.66
61	3.964	0.0378	0.1498	29,225	0.128	0.0323	0.967	195.1	201.8	50.3	260	0.776	0.53
62	3.968	0.0377	0.1496	27,200	0.250	0.0632	0.937	181.8	194.0	51.1	260	0.746	0.61

APPENDIX C

MATERIAL COMPOSITION

SAE 4130

ELEMENT	PER CENT OF TOTAL COMPOSITION
Carbon	0.31
Silicon	0.25
Manganese	0.53
Chromium	0.94
Molybdenum	0.20
Nickel	0.25 maximum
Phosphorus	0.01
Sulphur	0.02
Iron	balance

0.90 C

Carbon	0.90
Silicon	0.30
Manganese	1.40
Molybdenum	0.25
Phosphorus	0.01
Sulphur	0.03
Iron	balance

CRACK LENGTH EFFECTS ON TENSILE PROPERTIES OF ULTRA HIGH STRENGTH STEELS

An Abstract of a Thesis
Presented to the
Faculty of
San Diego State College

by
William Frederick Greene
August 1963

ABSTRACT

Statement of the problem. The tensile design stress can be increased in pressure vessels such as solid propellent rocket motor cases, when the effect of cracks is known. There is a critical crack length for the high strength materials used in this application such that cracks of shorter length do not reduce the case strength. This investigation determined the critical crack length for heat treated SAE 4130 and 0.90 carbon steels of 0.038 inch thickness in centrally cracked tensile specimens in 2, 3, and 4 inch widths at room temperature. Also, ductility of cracked specimens was reported.

Method. Rectangular specimens 12 inches long were centrally drilled and notched. Cracks of various lengths were generated at the notches by applying a tensile load to each specimen. SAE 4130 and 0.90 carbon steels were heat treated to tensile strengths of 225,000 and 270,000 psi respectively. Each specimen was fractured in tension slowly, and continuous ductility information was recorded.

Results and conclusions. Logarithmic curves relating the ratio, Net Tensile Strength/Ultimate Tensile Strength, to crack length showed the critical crack length in each steel for the widths tested. Four inch wide specimens in SAE 4130 and 0.90 per cent carbon steels were found to have critical crack lengths of

0.058 inch and 0.039 inch respectively. Retained ductility of specimens having the critical crack length was approximately 5 per cent and 1 per cent elongation in 2 inches respectively. Additional study appears desirable to find the critical crack length for infinitely wide sheets of these materials, and to determine more definite ductility relationships.

thesG753
The effect of crack length on tensile pr
3 2768 002 13894 3
DUDLEY KNOX LIBRARY